Shaking Table Tests on Deficient RC Frames Strengthened with FRPs and Pos-Tensioned Metal Straps

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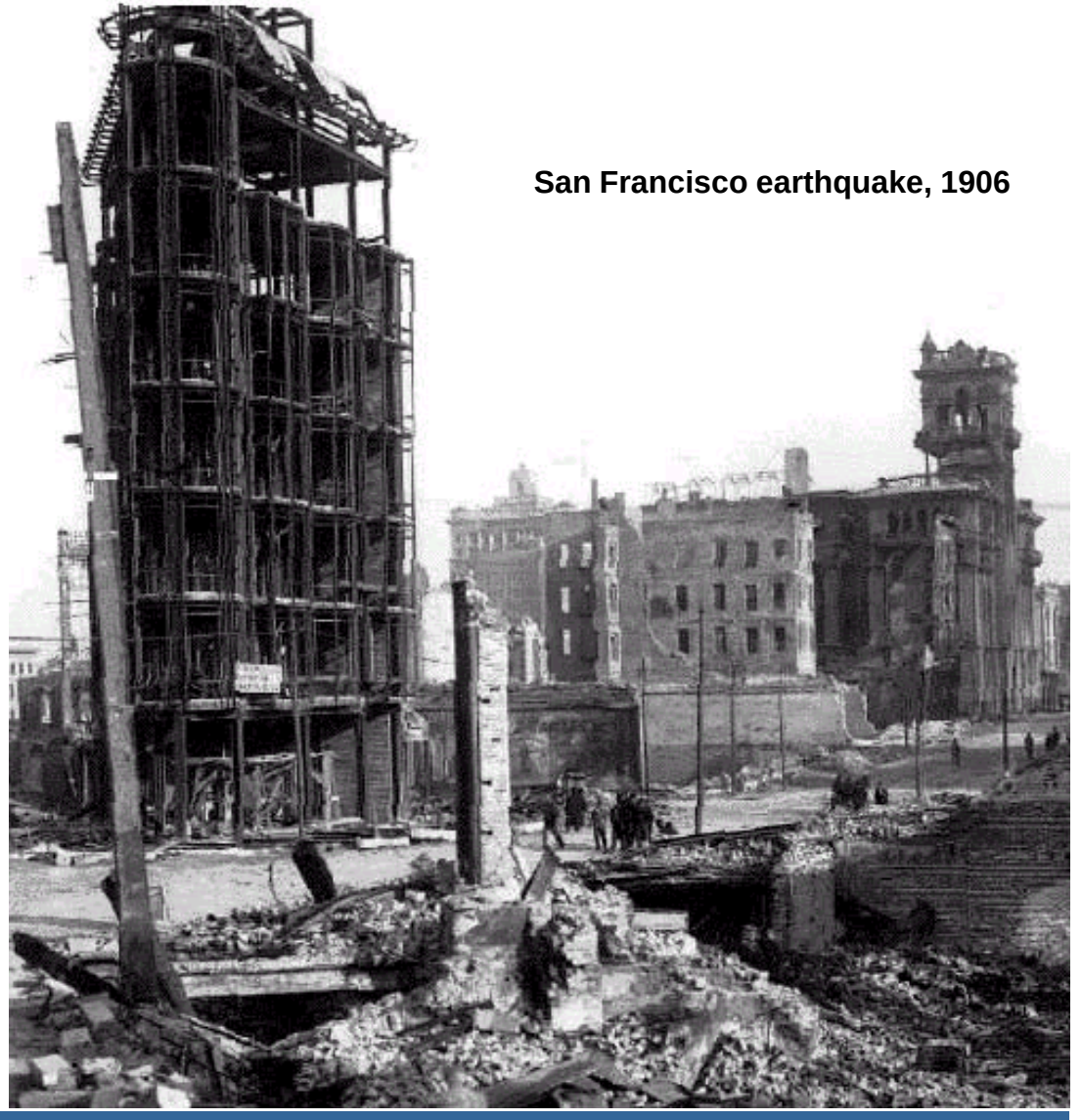
Outline

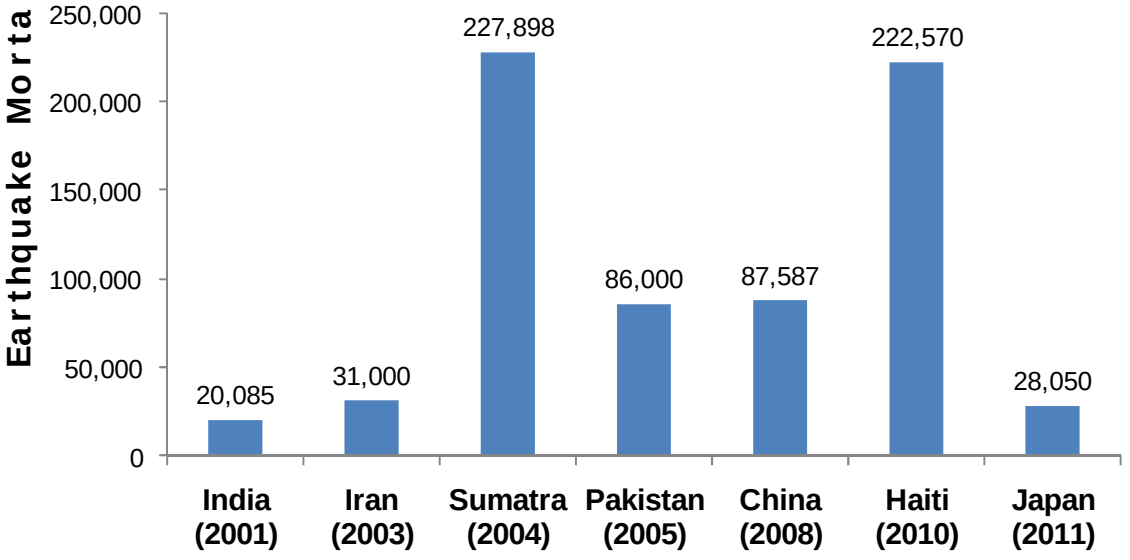
- Introduction
- Strengthening Using FRPs
- Strengthening Using PTMS
- Efficiency of PTMS technique
- BANDIT Project



San Francisco earthquake, 1906

Introduction

Severe damage and extensive mortality



In the past 10 years loss of human life due to earthquakes was around 73,000/per year

Introduction

Recent Major Earthquakes

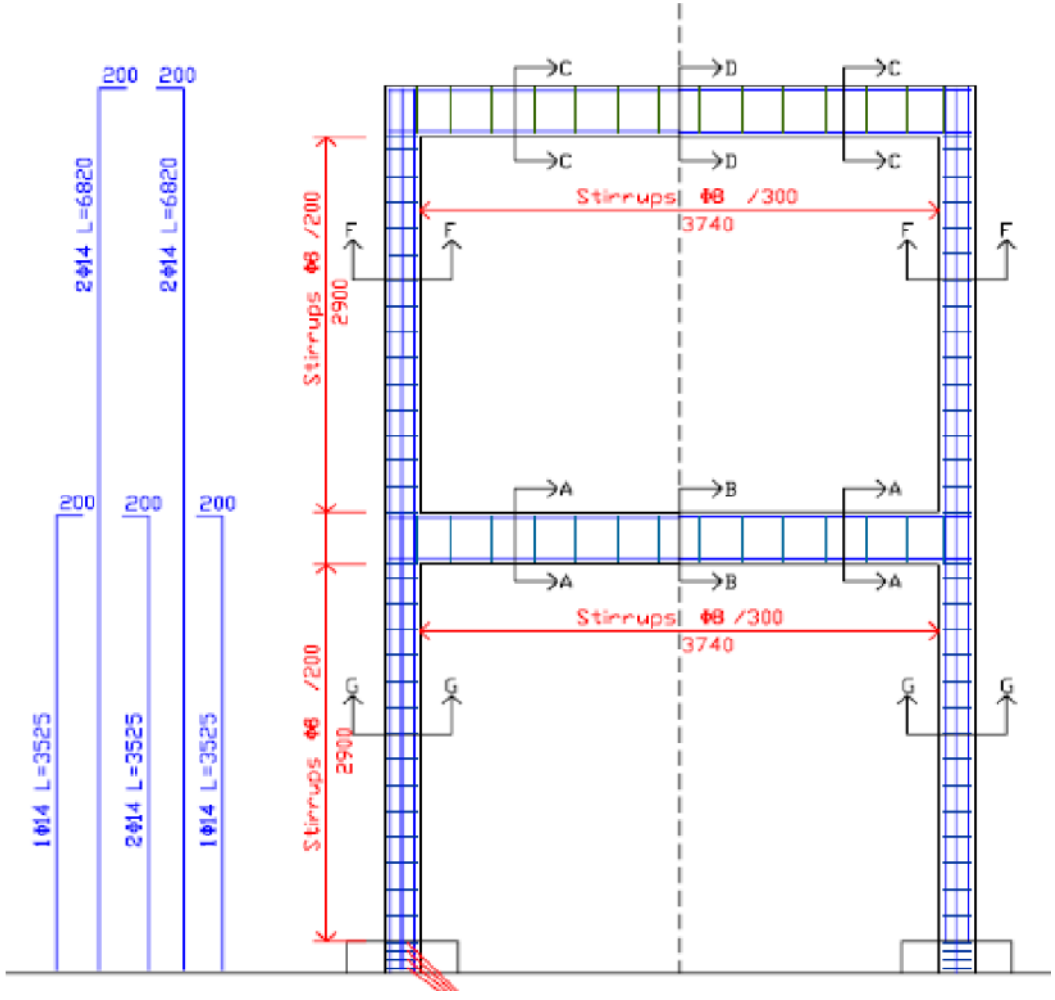
Date	Location	Magnitude	Fatalities
March 11, 2011	Japan	9.0	28,050
Feb 22, 2011	New Zealand	6.3	65
Feb 27, 2010	Chile	8.8	723
Jan 12, 2010	Haiti	7.0	230,000
May 12, 2008	Eastern Sichuan, China	7.9	87652
May 26, 2006	Java, Indonesia	6.3	5,749
Oct 8, 2005	Pakistan	7.6	> 86,000
Dec 26, 2004	Sumatra, Indonesia	9.3	283,106
Dec 26, 2003	Bam, Iran	6.6	31,000
May 21, 2003	Boumerdes, Algeria	6.8	2,266
Jan 26, 2001	India	7.9	> 13,000

Bam- 2003 Earthquake

Strengthening Using FRPs

Strengthening Using FRP Composites

Strengthening Using FRPs



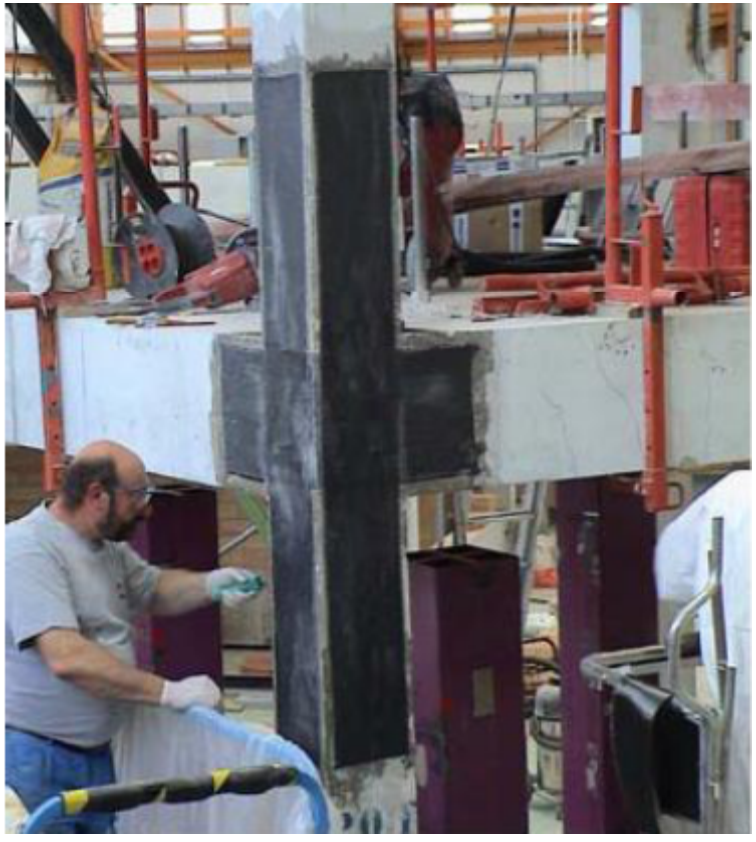
Design according to old practice

Strengthening Using FRPs

Damage in the joints

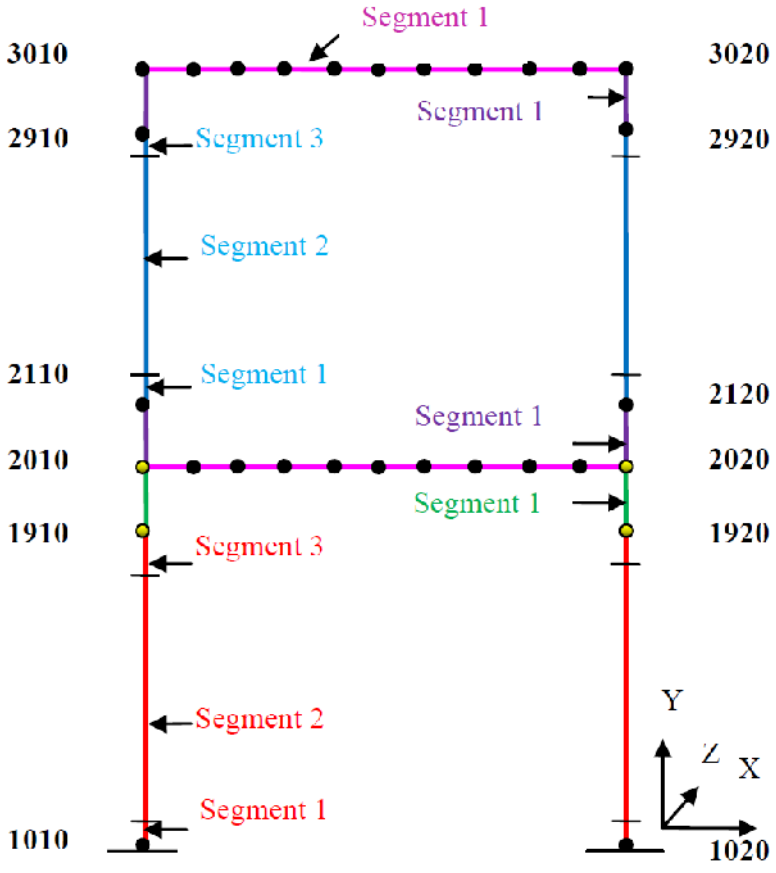
Strengthening Using FRPs

Strengthening Programme



Strengthening Using FRPs

Analytical Model in Drain 3dx



Group 1 : Column 1

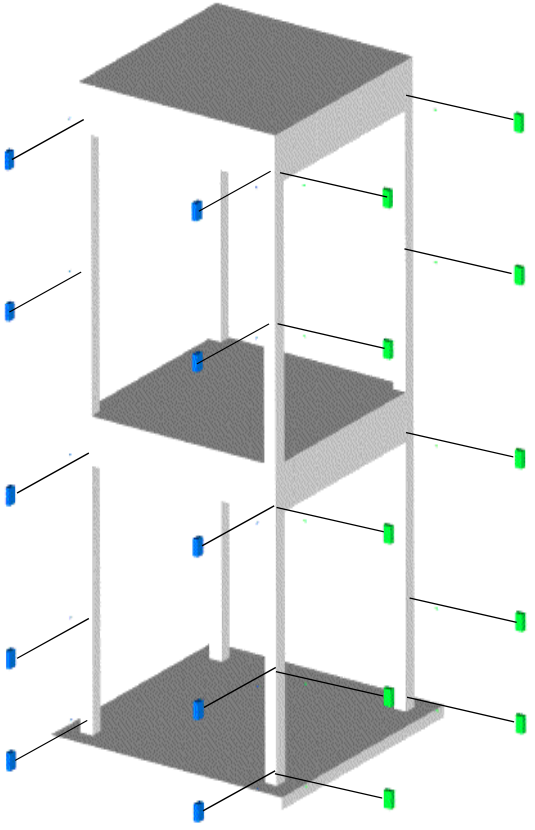
Group 2 : Column 2

Group 3 : Beam

Group 4 : Column Joint 1

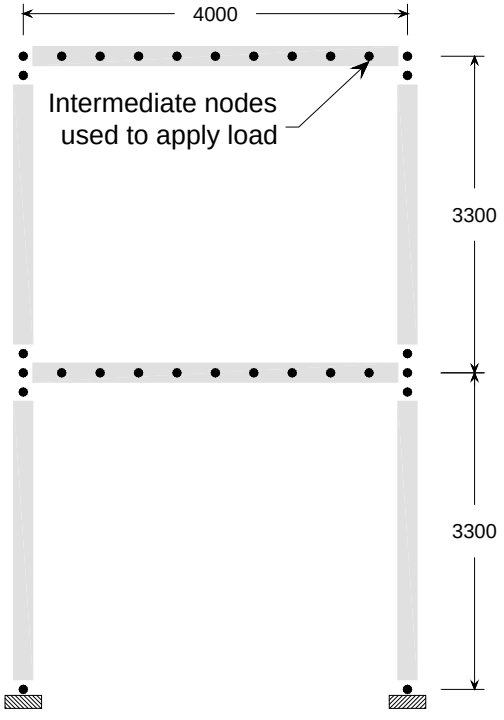
Group 5 : Column Joint 2

Connection Hinge

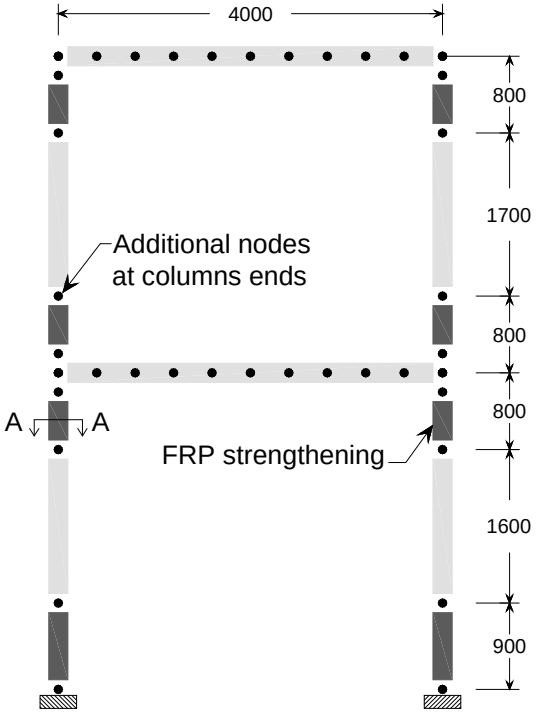


Strengthening Using FRPs

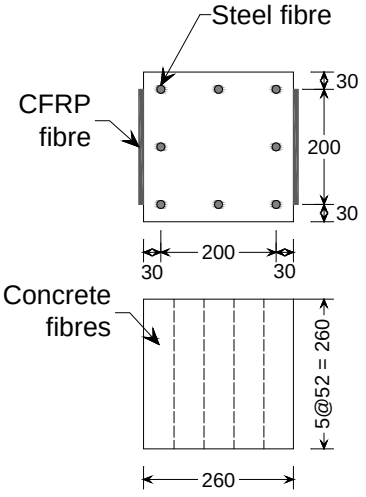
Analytical Model in Drain 3dx



Bare frame



FRP-strenghtened frame

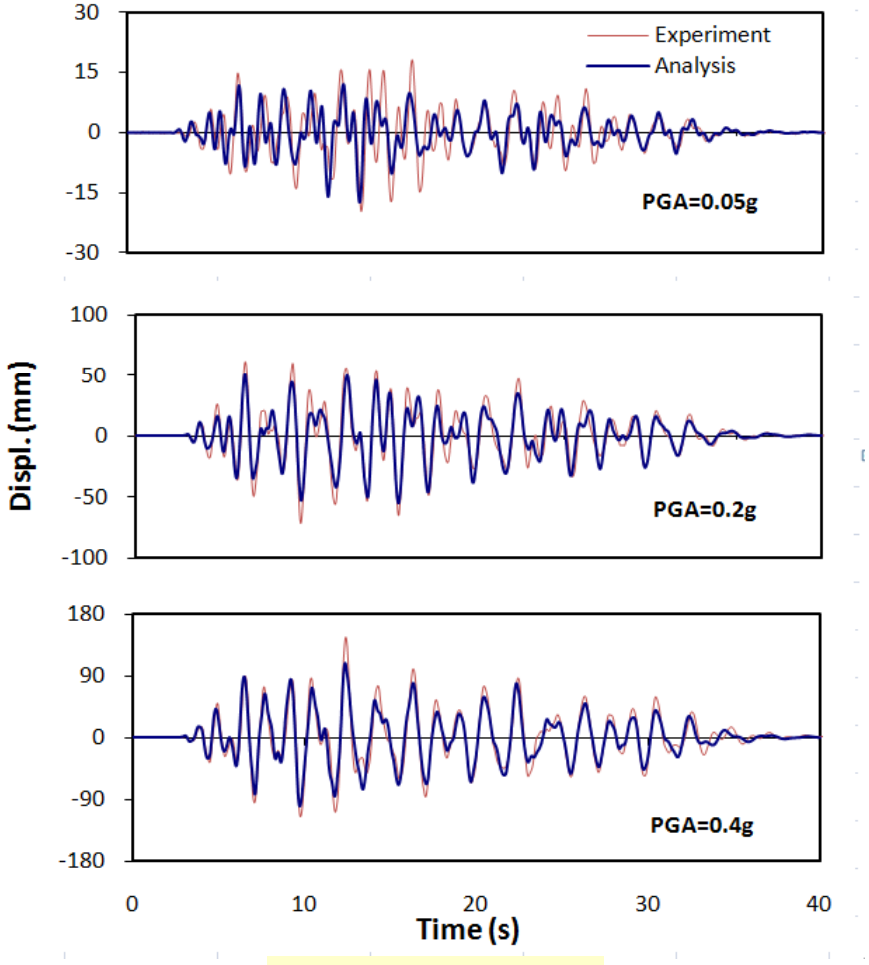


Section A-A

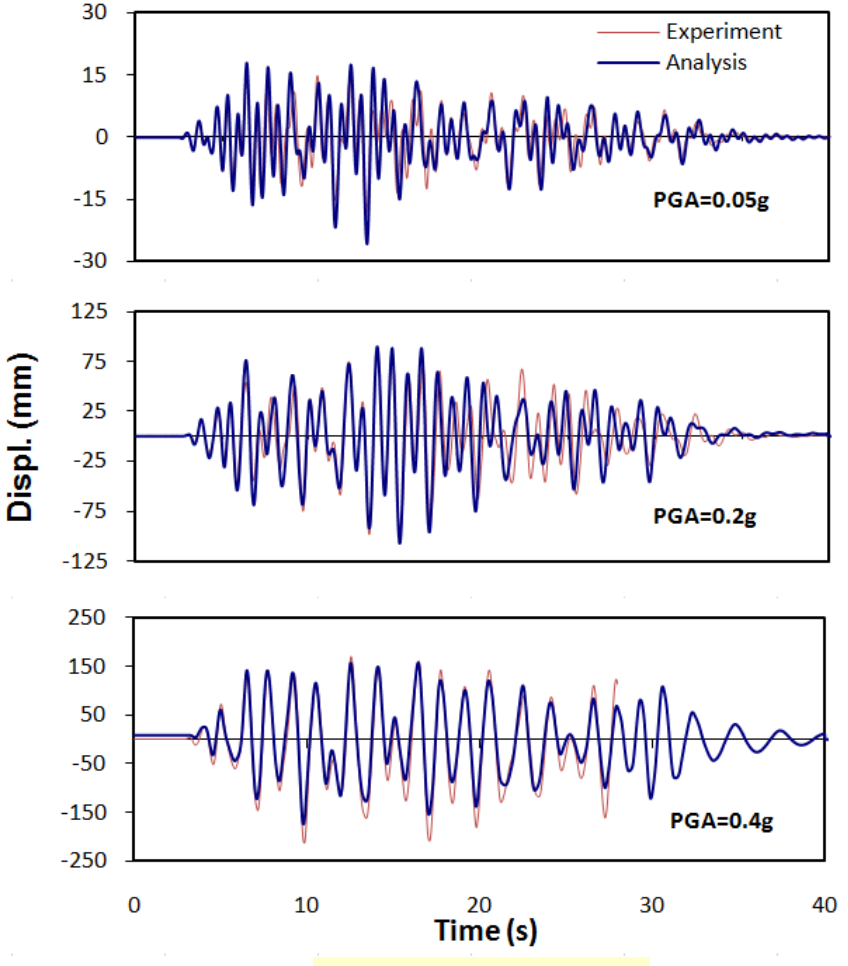
Discretisation
of elements
(in mm)

Strengthening Using FRPs

Nonlinear Dynamic Analysis



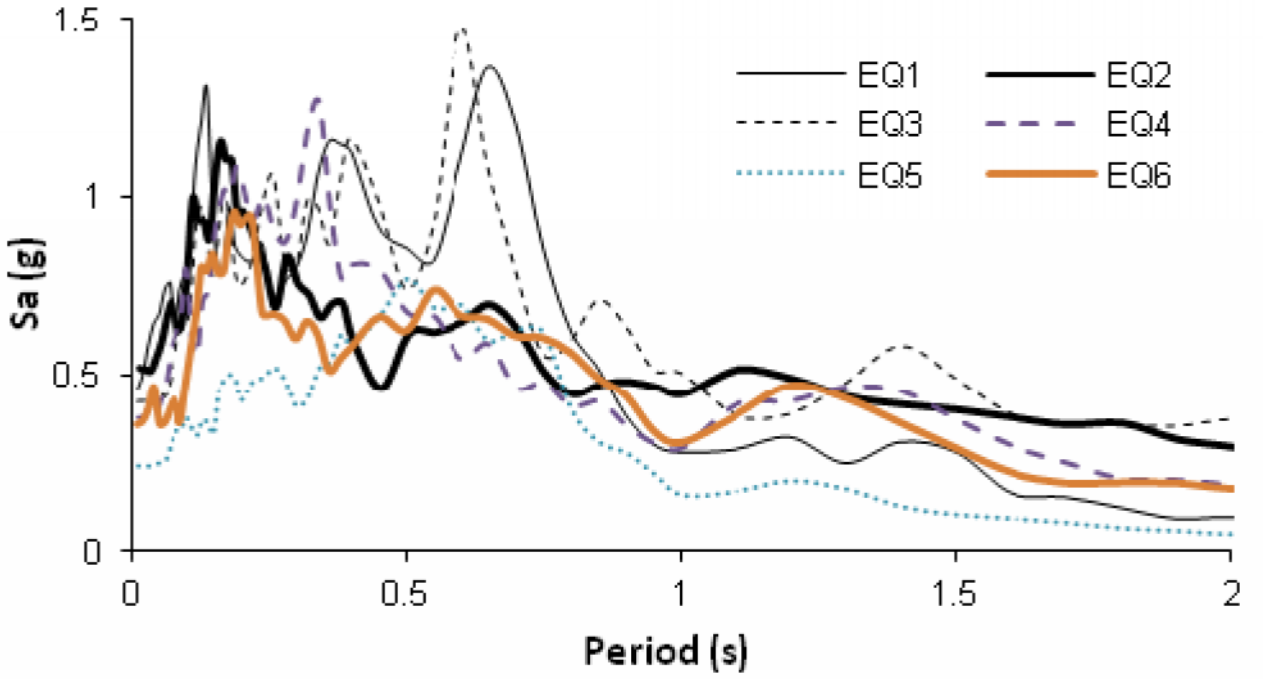
1st Storey



2nd Storey

Strengthening Using FRPs

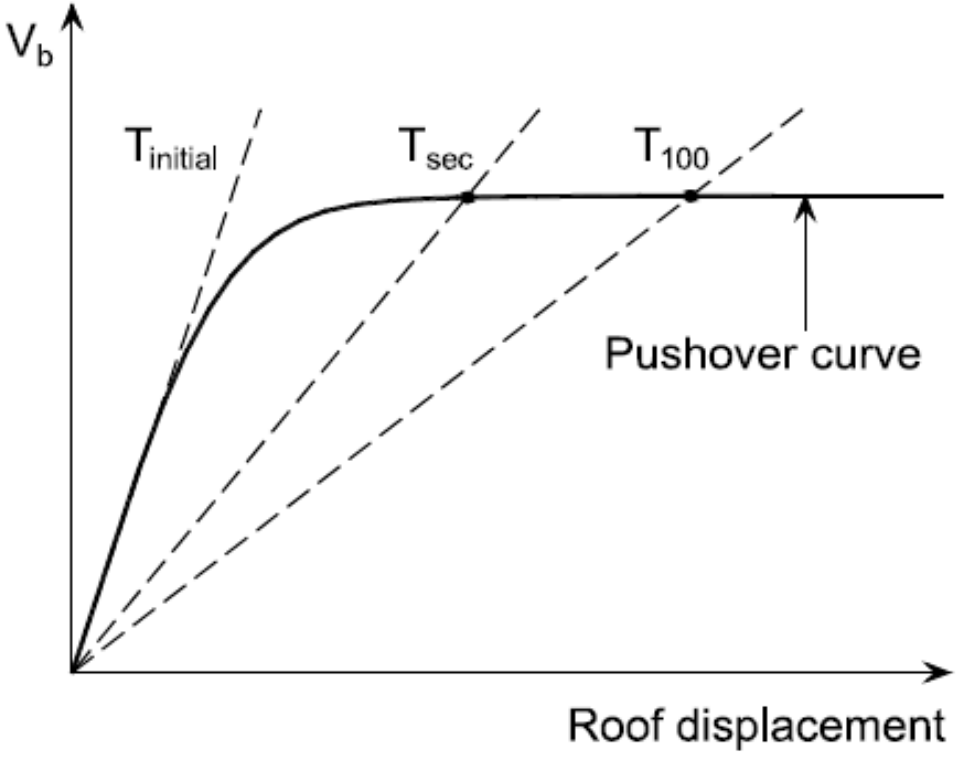
Evaluation of FRP Strengthening



Six Design Earthquakes (Soil type C)

Strengthening Using FRPs

Evaluation of FRP Strengthening

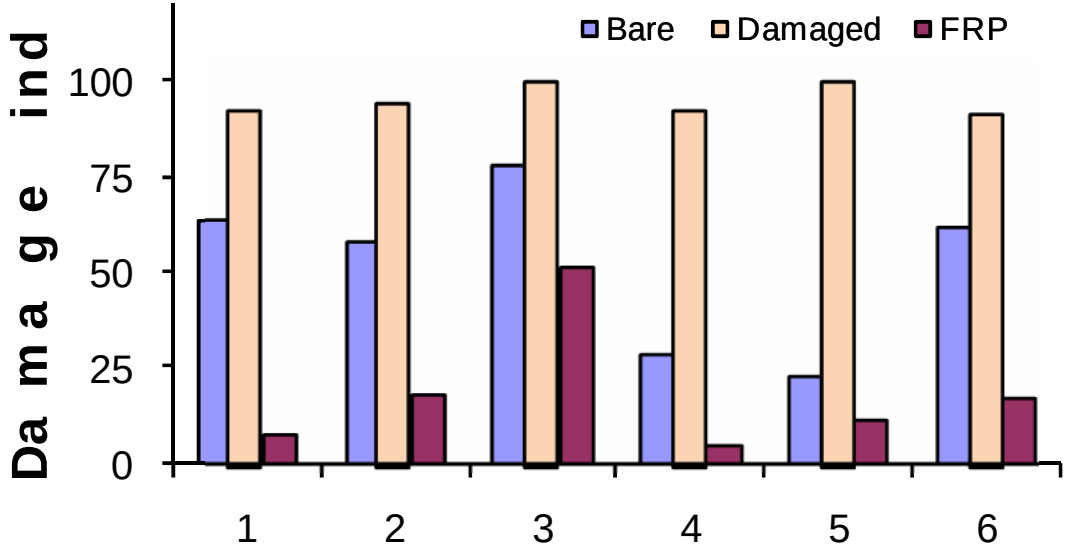


$$DI = 100 \cdot \left(\frac{T_{sec} - T_{initial}}{T_{100} - T_{initial}} \right)$$

Global Damage Index (DI)

Strengthening Using FRPs

Evaluation of FRP Strengthening



Global Damage Index (DI)

Strengthening Using PTMS

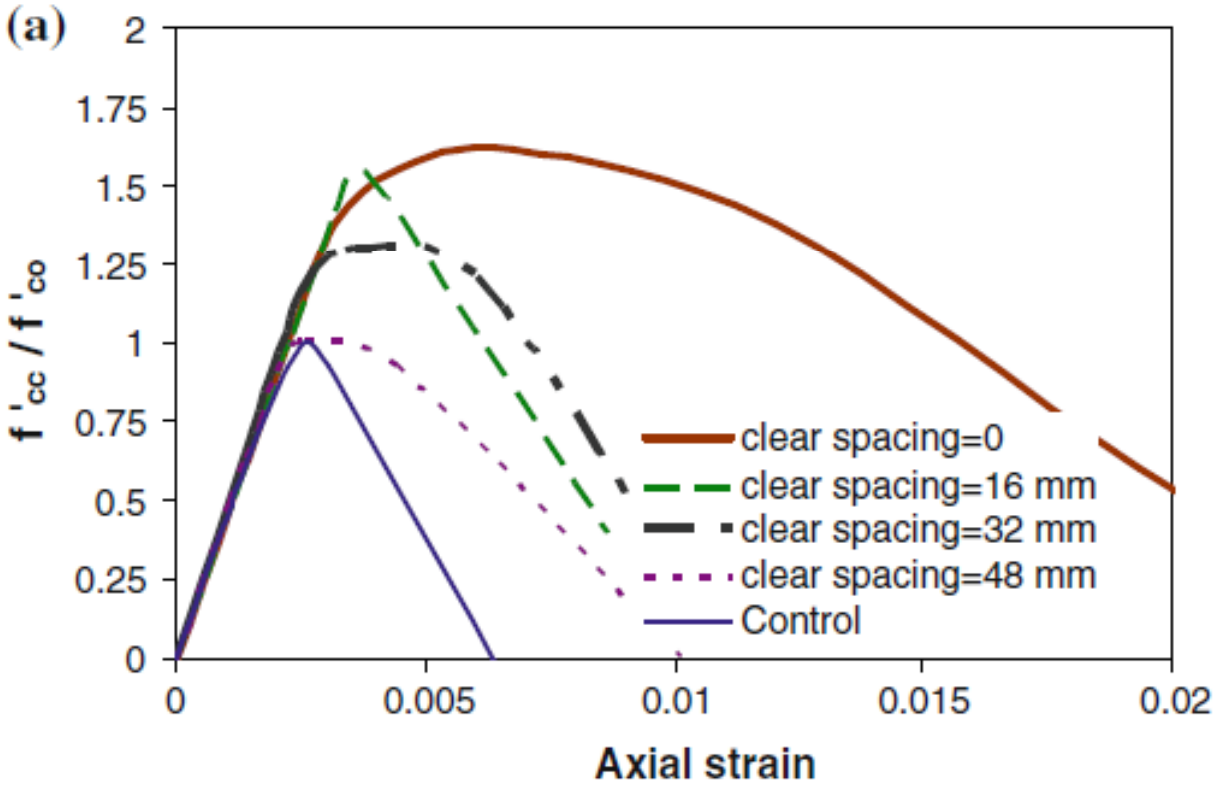
Post Tension Metal Straps (PTMS)

Strapping device used in the packaging industry

Axial Compressive Tests (Moghaddam et. al.)

Strengthening Using PTMS

Efficiency of the PTMS technique



Enhancement of strength

Improving of stress-strain characteristics

Enhancement of energy dissipation and hence, member ductility

Strengthening Using PTMS

Strengthening of RC elements

PTMS for strengthening of Columns

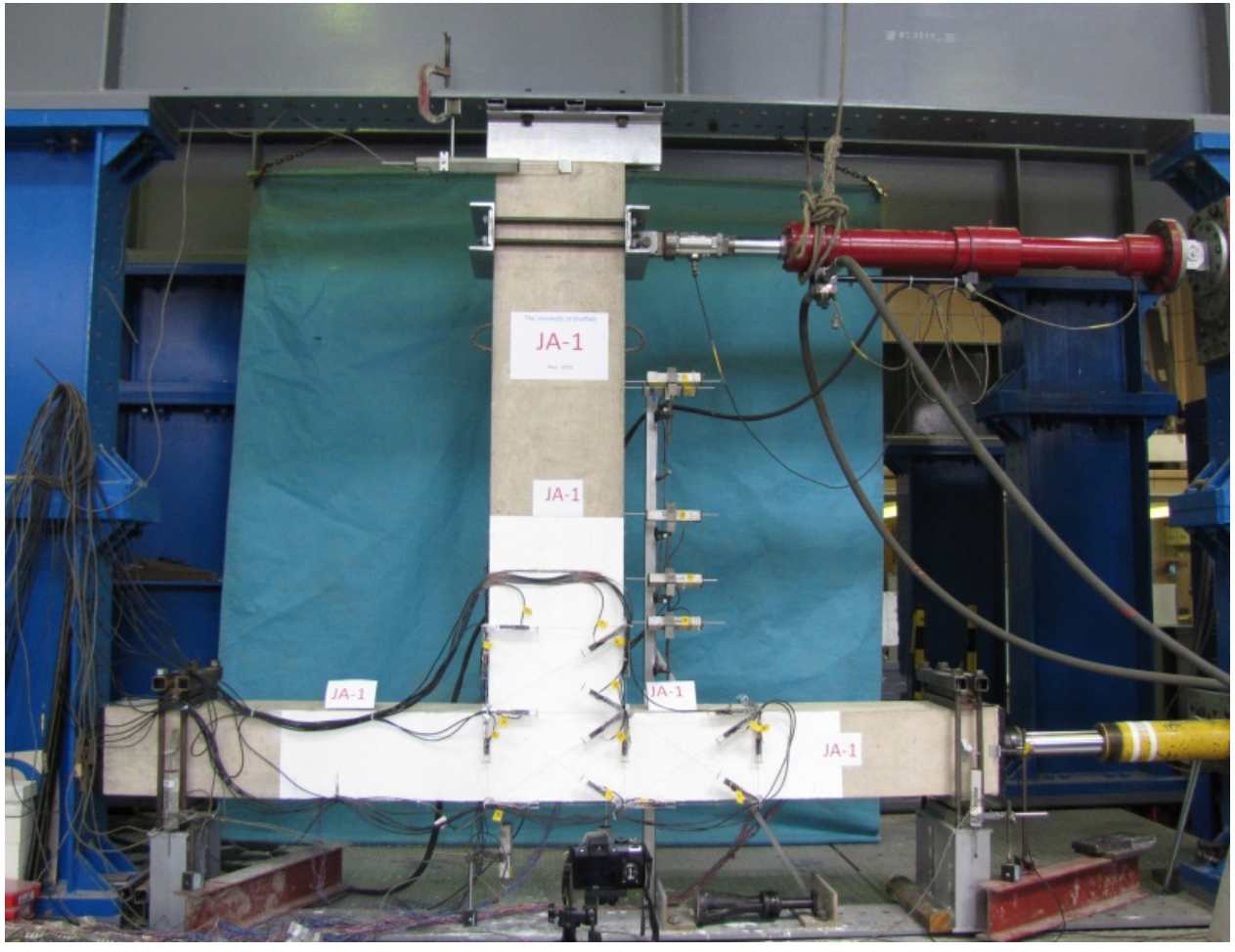
PTMS for strengthening of Beams

Strengthening Using PTMS

Efficient and simple !

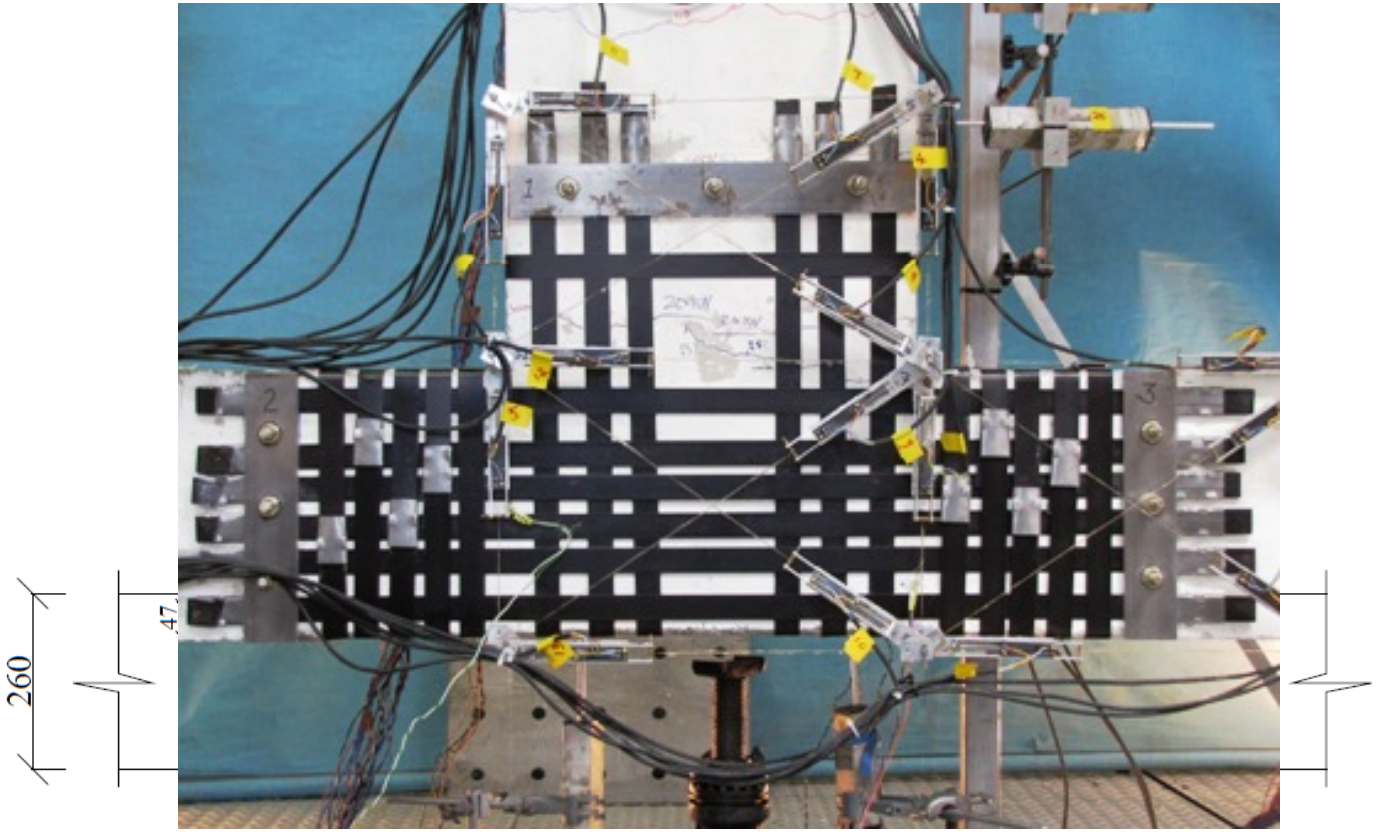
Strengthening Using PTMS

Strengthening of Connections



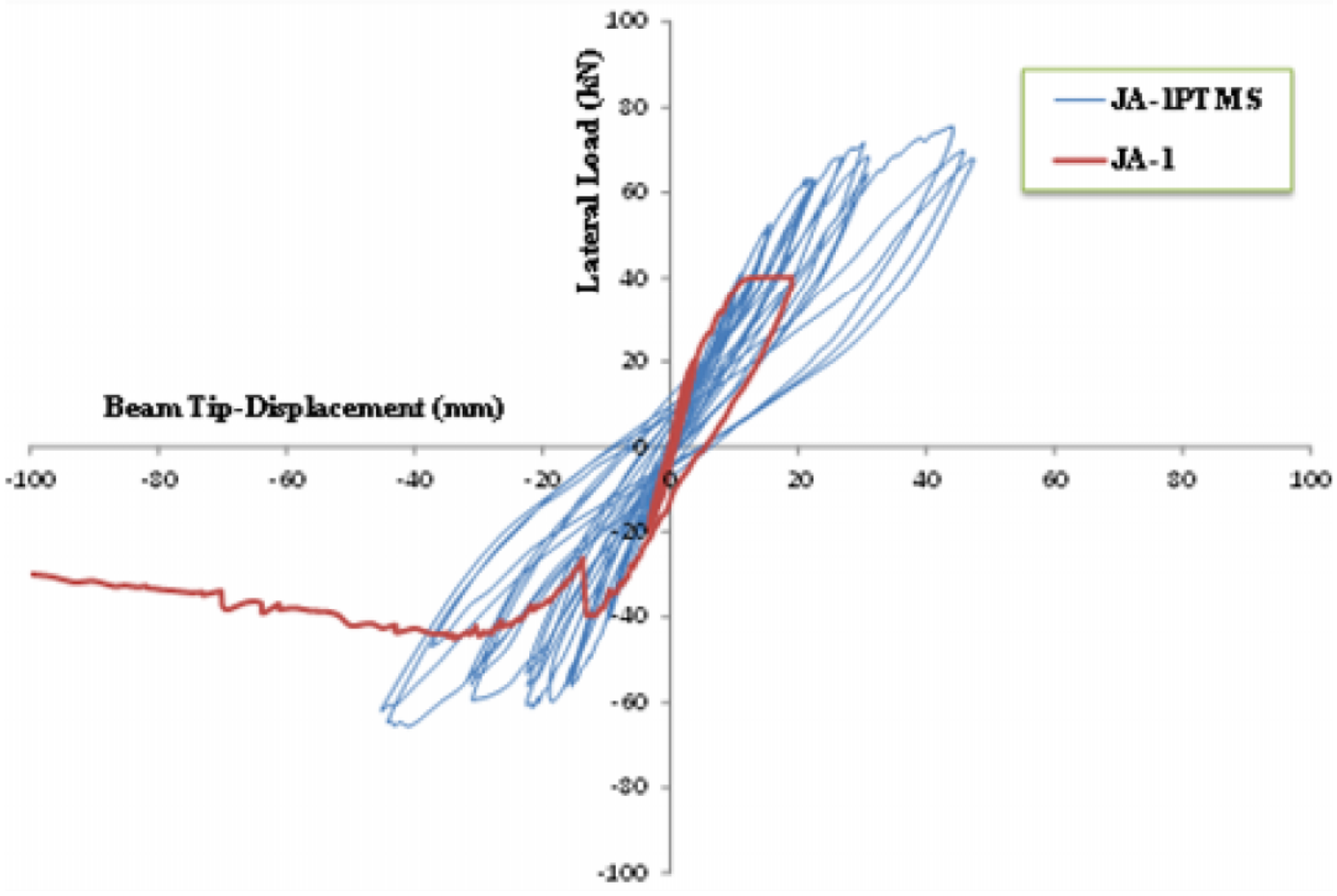
Strengthening Using PTMS

Strengthening of Connections



Strengthening Using PTMS

Efficiency for connections



Strengthening Using PTMS

Confinement model	Confined concrete strength	Strain at peak stress
Richart et al. [1]	$f'_{cc} = f'_{co}[1 + 4.1 f_{le}]$	$\varepsilon_{cc} = \varepsilon_{co}\left(1 + 20.5\,\frac{f_l}{f'_{co}}\right)$
Newman and Newman [21]	$f'_{cc} = f'_{co}\left[1 + 3.7\left(\frac{f_{le}}{f'_{co}}\right)^{0.86}\right]$	
Sheikh and Uzumeri [8]	$f'_{cc} = k \cdot f'_{co};\ k = 1.0 + \frac{b_c^2}{140 P_{acc}}\left[\left(1 - \frac{n s_1^2}{5.5 b_c^2}\right)\left(1 - \frac{s}{2b_c}\right)^2\right]\sqrt{\rho_s f_{sh}}$	$\varepsilon_{cc} = 80 K f'_c \times 10^{-6}$
Park et al. [22]	$f'_{cc} = f'_{co}\left(1 + 2\,\frac{f_l}{f'_c}\right)$	$\varepsilon_{cc} = \varepsilon_{co}\left(1 + 2\,\frac{f_l}{f'_c}\right)$
Ahmad and Shah [11]	$f'_{cc} = f'_{co}\left[1 + 4.2556\left(\frac{f_l}{f'_{co}}\right)\right]$ if $\frac{f_l}{f'_{co}} < 0.68$ $f'_{cc} = f'_{co}\left[1.7757 + 3.1171\left(\frac{f_l}{f'_{co}}\right)\right]$ if $\frac{f_l}{f'_{co}} > 0.68$	
Fafitis and Shah [23]	$f'_{cc} = f'_{co} + \left(1.15 + \frac{3048}{f'_c}\right) f_l$	$\varepsilon_{cc} = 14.61 \times 10^{-7} f'_{co} + 0.0296\,\frac{f_l}{f'_{co}} + 0.00195$
Saatcioglu and Razvi [10]	$f'_{cc} = f'_{co} + 6.7(f_{le})^{0.83}$	$\varepsilon_{cc} = \varepsilon_{co}\left(1 + 33.5\left(\frac{f_{le}}{f'_{co}}\right)^{0.83}\right)$
Mander et al. [4]	$f'_{cc} = f'_{co}\left[2.254\sqrt{1 + 7.94\,\frac{f_l}{f'_{co}}} - 2\,\frac{f_l}{f'_{co}} - 1.254\right]$	$\varepsilon_{cc} = \varepsilon_{co}\left[1 + R\left(\frac{f_{cc}}{f_{co}} - 1\right)\right]$
Karabinis and Kiousis [24]	$f'_{cc} = f'_{co} + 4.269 f_l^{0.587}$	
Hoshikuma et al. [25]	$f'_{cc} = f'_{co}\left(1 + 7.6\,\frac{f_{ley}}{f_{co}}\right)$	$\varepsilon_{cc} = 0.002 + 0.066\,\frac{f_{le}}{f_{co}}$
Bousalem and Chikh [26]	$f'_{cc} = f'_{co}\left(1 + 0.8\,\frac{f_{ley}}{\sqrt{f_{co}}}\right)$	$\varepsilon_{cc} = \varepsilon_{co}\left(1 + 5.4\,\frac{f_{le}}{\sqrt{f'_{co}}}\right)$
Cusson and Paultre [12]	$f'_{cc} = f'_{co}\left(1 + 2.1\left(\frac{f_{le}}{f'_{co}}\right)^{0.7}\right)$	$\varepsilon_{cc} - \varepsilon_{co} = 0.21\left(\frac{f_{le}}{f_{co}}\right)^{1.7}$
Attard and Setunge [27]	$\frac{f_{cc}}{f_c} = \left(\frac{f_l}{f_t} + 1\right)^k;\ k = 1.25\left(1 + 0.062\,\frac{f_{le}}{f_{co}}\right)(f_{co})^{-0.21}$	$\varepsilon_{cc} = \varepsilon_{co}\left(1 + (17 - 0.06 f_{co})\left(\frac{f_{le}}{f_{co}}\right)\right)$
CEB model code 90 [28]	$f'_{cc} = f'_{co}\left(1 + 5\left(\frac{f_{ley}}{f'_{co}}\right)\right)$ $\alpha\omega_w \le 0.1$ $f'_{cc} = f'_{co}\left(1.125 + 2.5\left(\frac{f_{ley}}{f'_{co}}\right)\right)$ $\alpha\omega_w \ge 0.1$	$\varepsilon_{cc} = \varepsilon_{co}\left(1 + 5\left(\frac{f_{ley}}{f'_{co}}\right)\right)^2$ $\varepsilon_{cc} = \varepsilon_{co}\left(1.125 + 2.5\left(\frac{f_{ley}}{f'_{co}}\right)\right)^2$

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Aims and Objectives

- Investigate the vulnerability of substandard RC structures and contribute towards the development of appropriate assessment techniques.
- Evaluate the efficiency of different strengthening configurations (pre-damage condition) using Post-tensioned Metal Strapping (PTMS) technique and develop cost efficient rehabilitation strategies (post-damage condition).
- Test the effect of different deficient anchorage arrangements on the seismic behaviour of low- strength RC beam-column joints.

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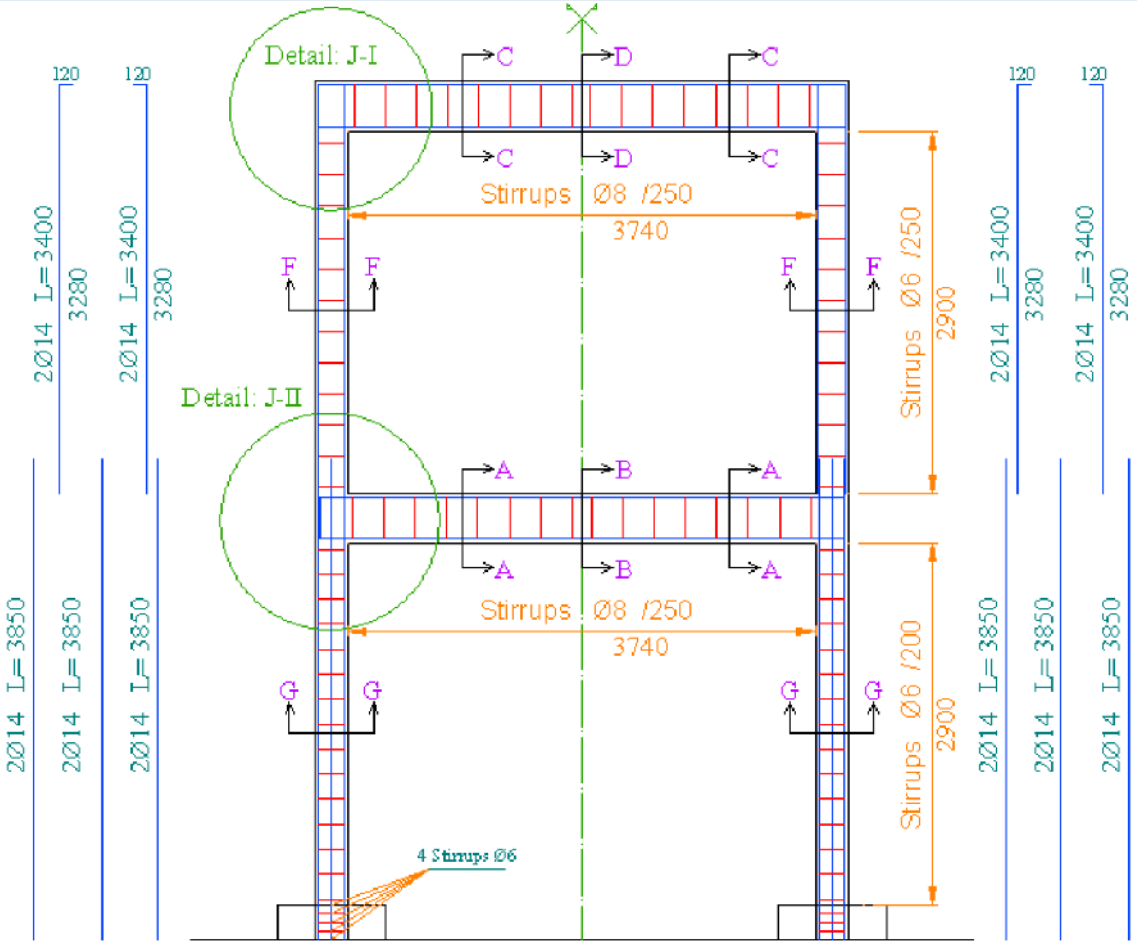

A substandard RC frame is designed to suffer from low strength concrete and poor detailing in joints and columns

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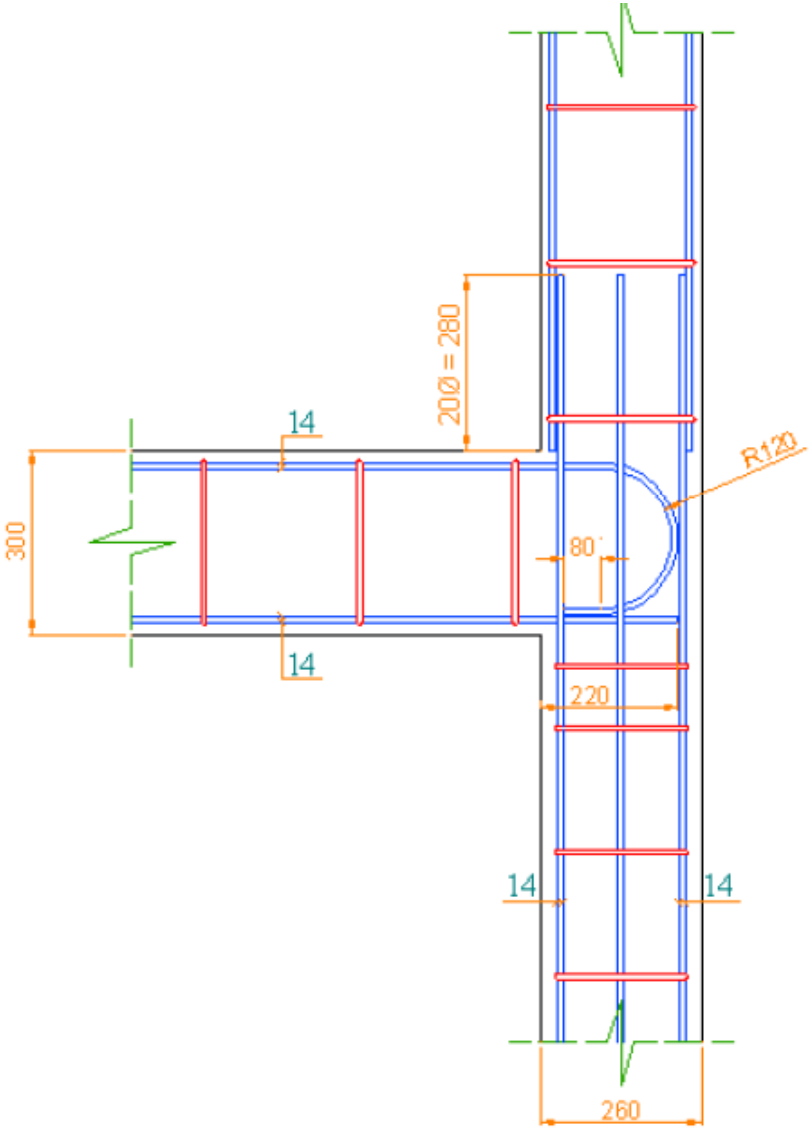
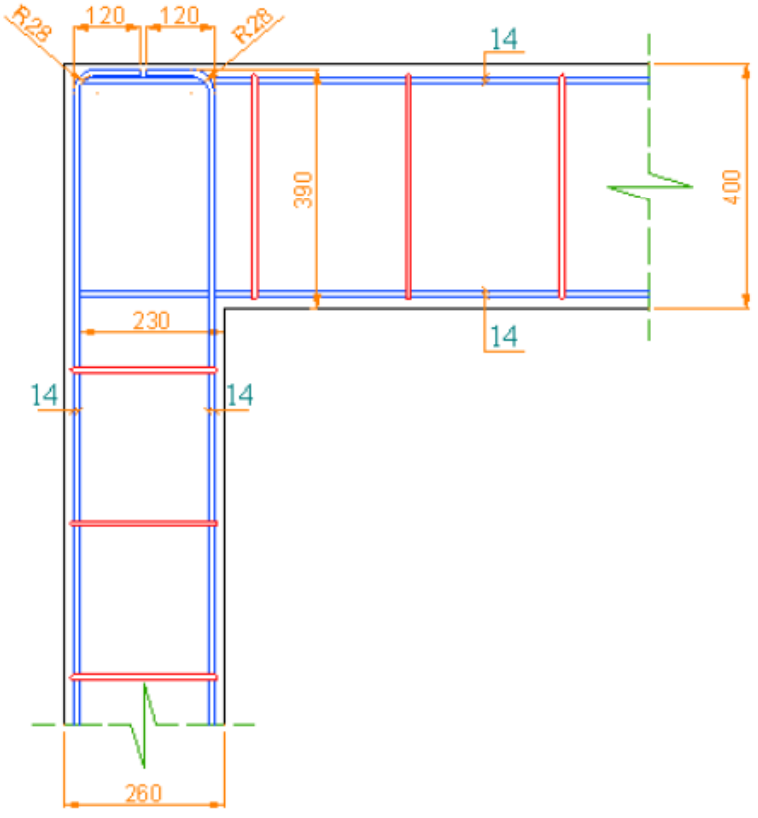
Anchorage Details





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The University of Nottingham

Low-strength concrete

Table 1. Mix design for low-strength concrete according to ACI procedure

Required average compressive strength at 28 days	**15 MPa**
Slump required	75 to 100 mm
Nominal maximum size of coarse aggregate	20 mm
Dry rodded mass of coarse aggregate	1600 kg/m^3
Fineness modulus of fine aggregate	2.6
Bulk specific gravity of coarse and fine aggregate	2.6
W/C ratio	0.82
Mixing water quantity	240 kg/m^3
Cement content	293 kg/m^3
Dry bulk volume of coarse aggregate	0.66
Coarse aggregate content	1056 kg/m^3
Unit weight of concrete	2355 kg/m^3
Fine aggregate content	766 kg/m^3
Results	
Cement	293 kg/m^3
Fine aggregate	766 kg/m^3
Coarse aggregate	1056 kg/m^3
Added water	240 kg/m^3

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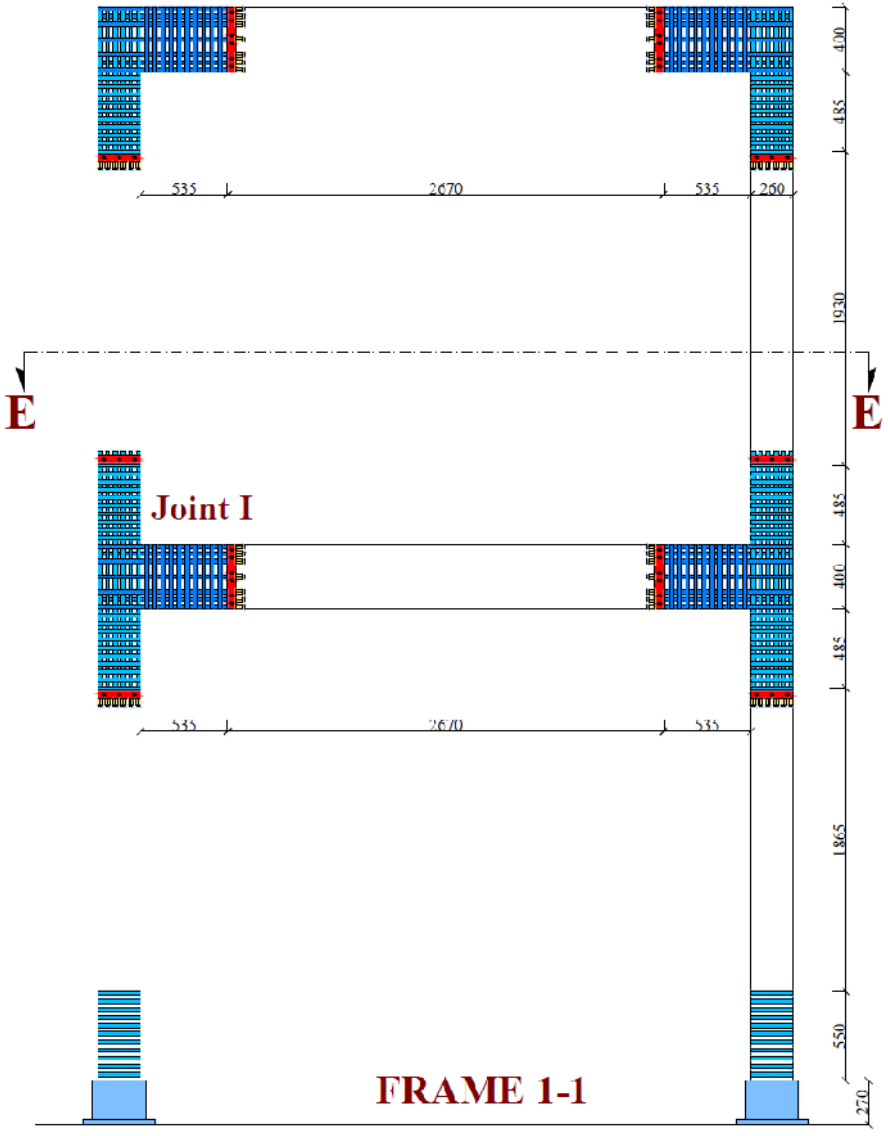

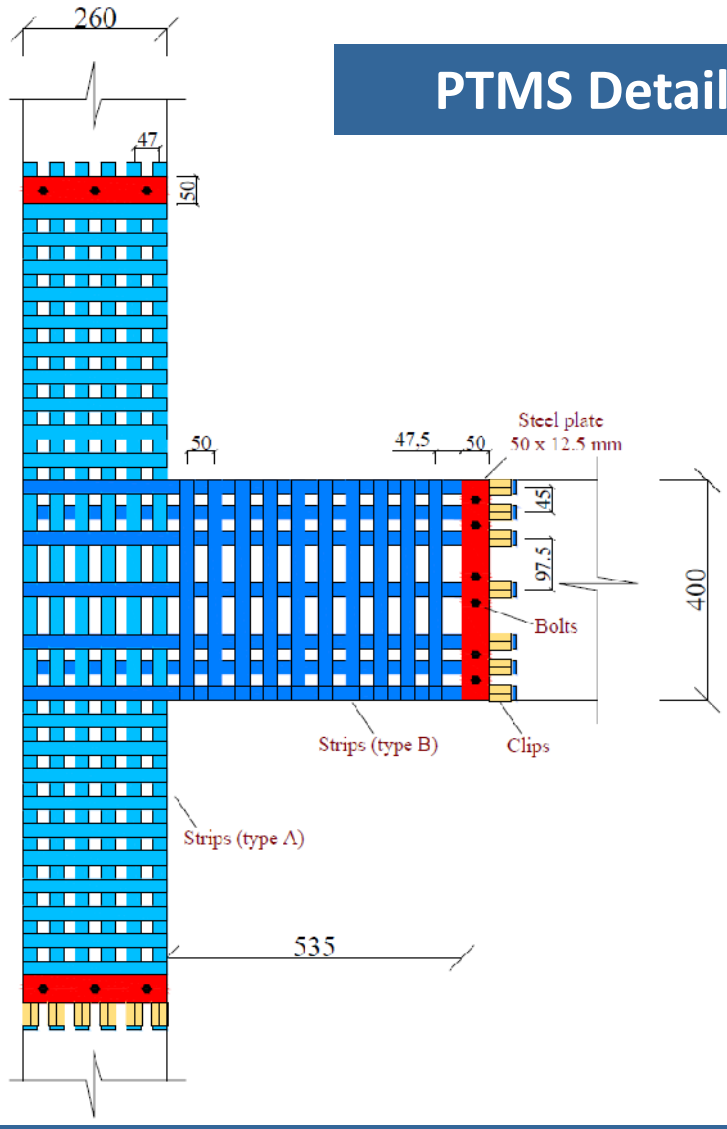

PTMS Detailing

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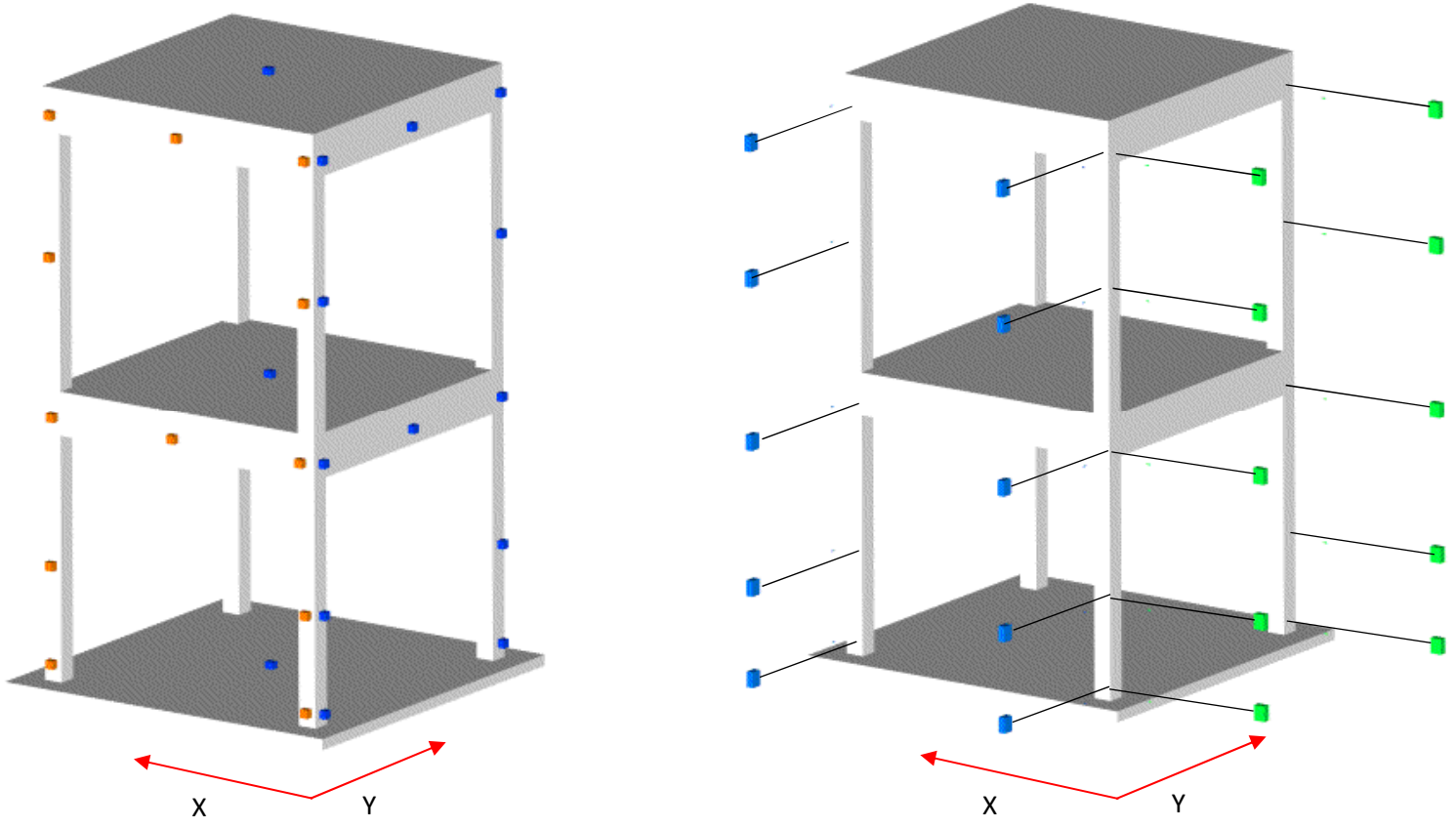
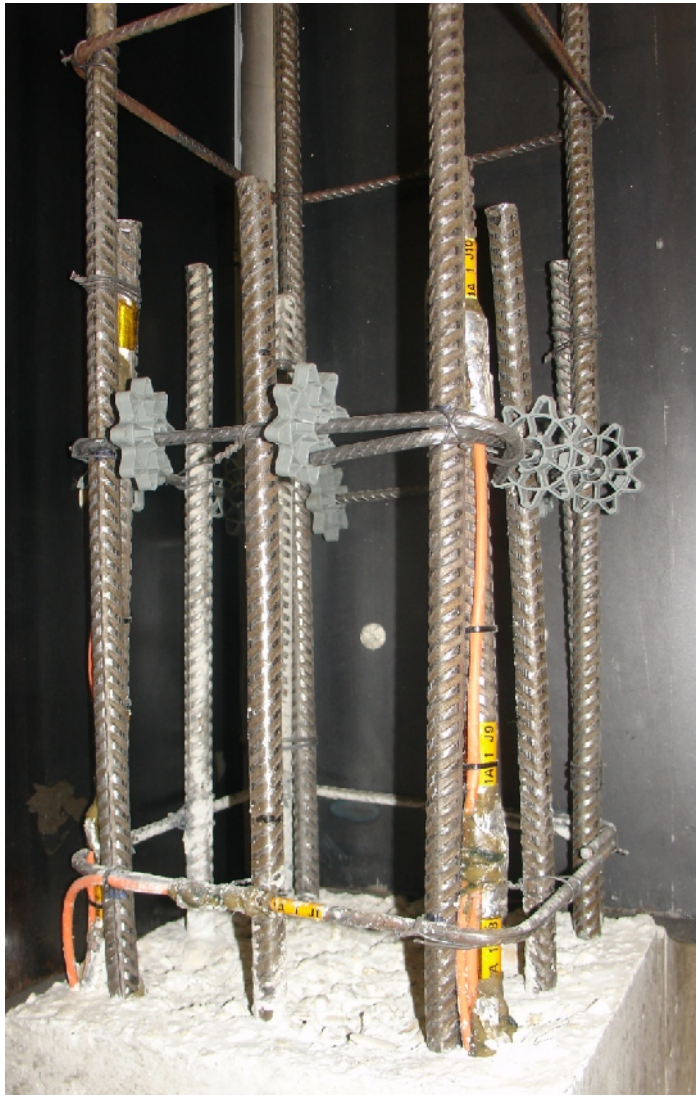
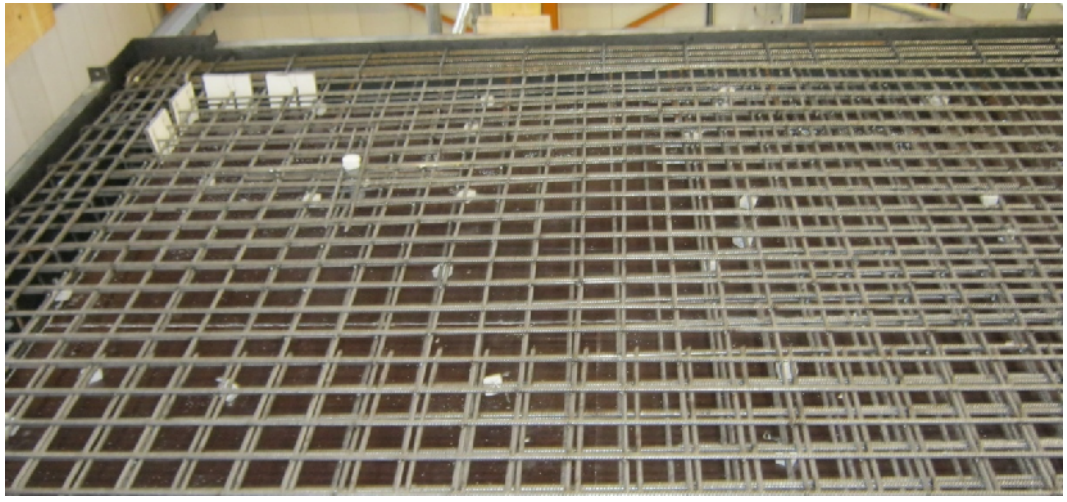
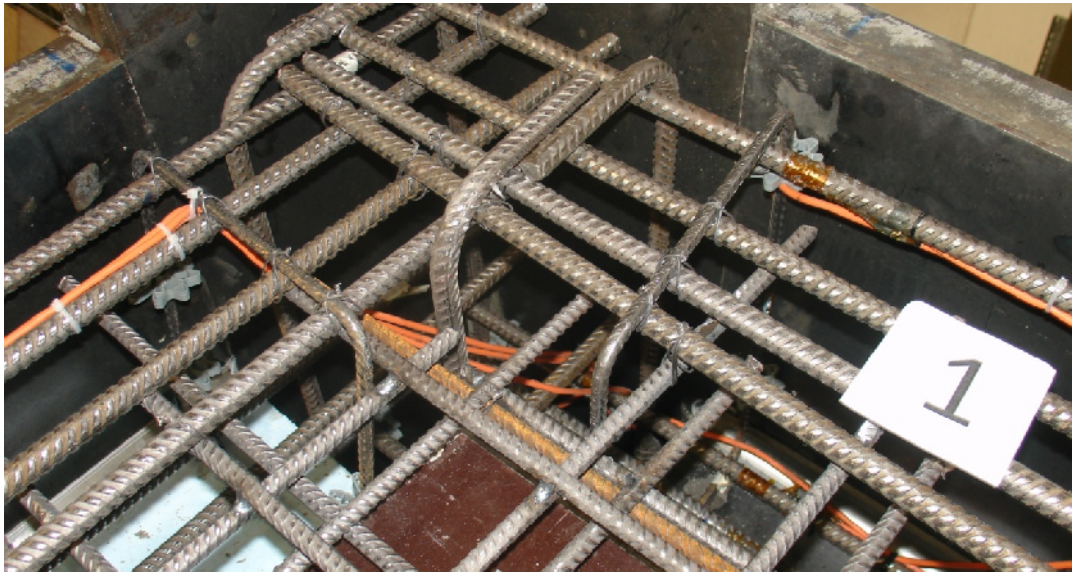


Location of acceleration transducers (left) and displacement transducers (right)

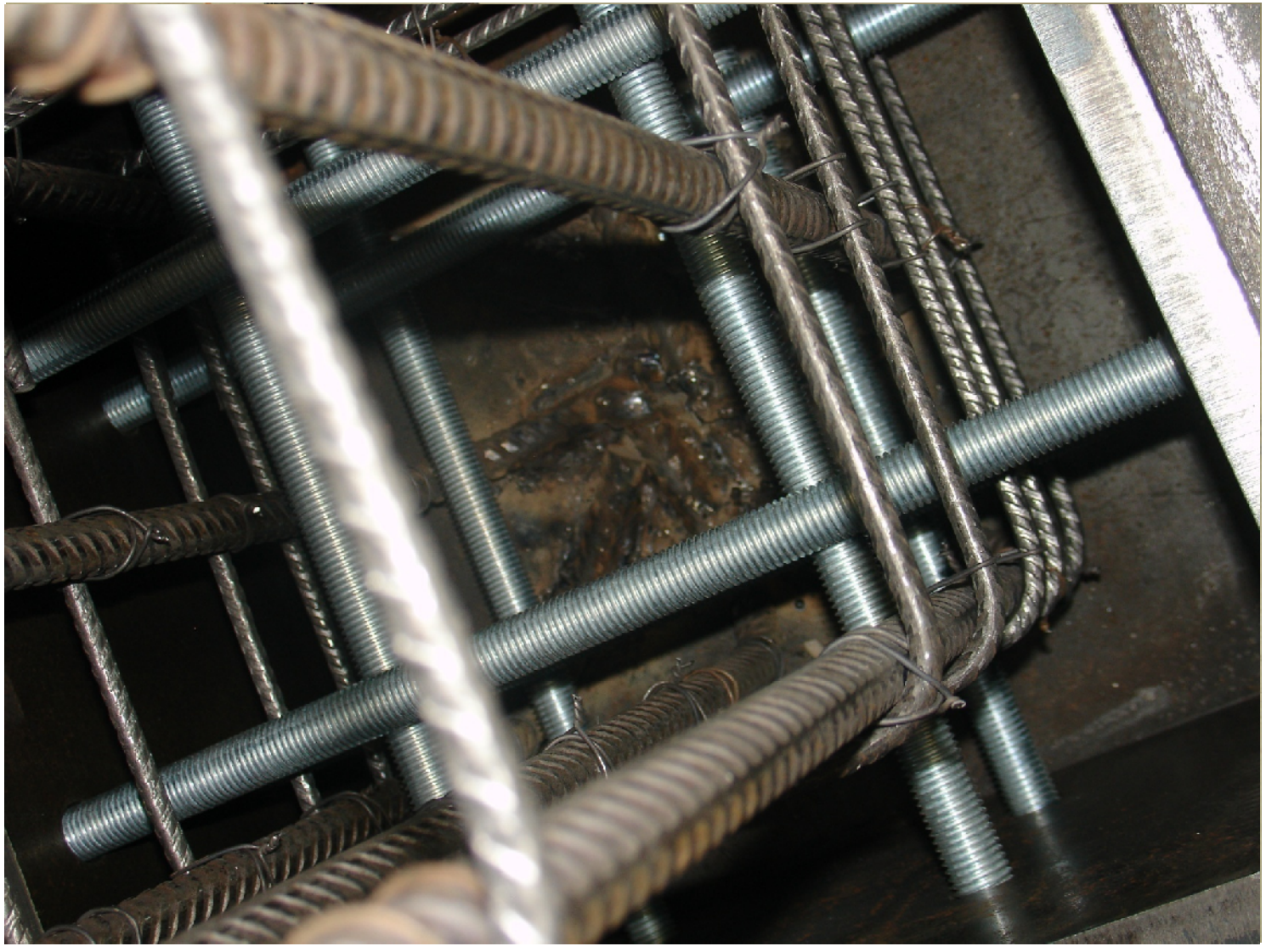
Reinforcement Detailing







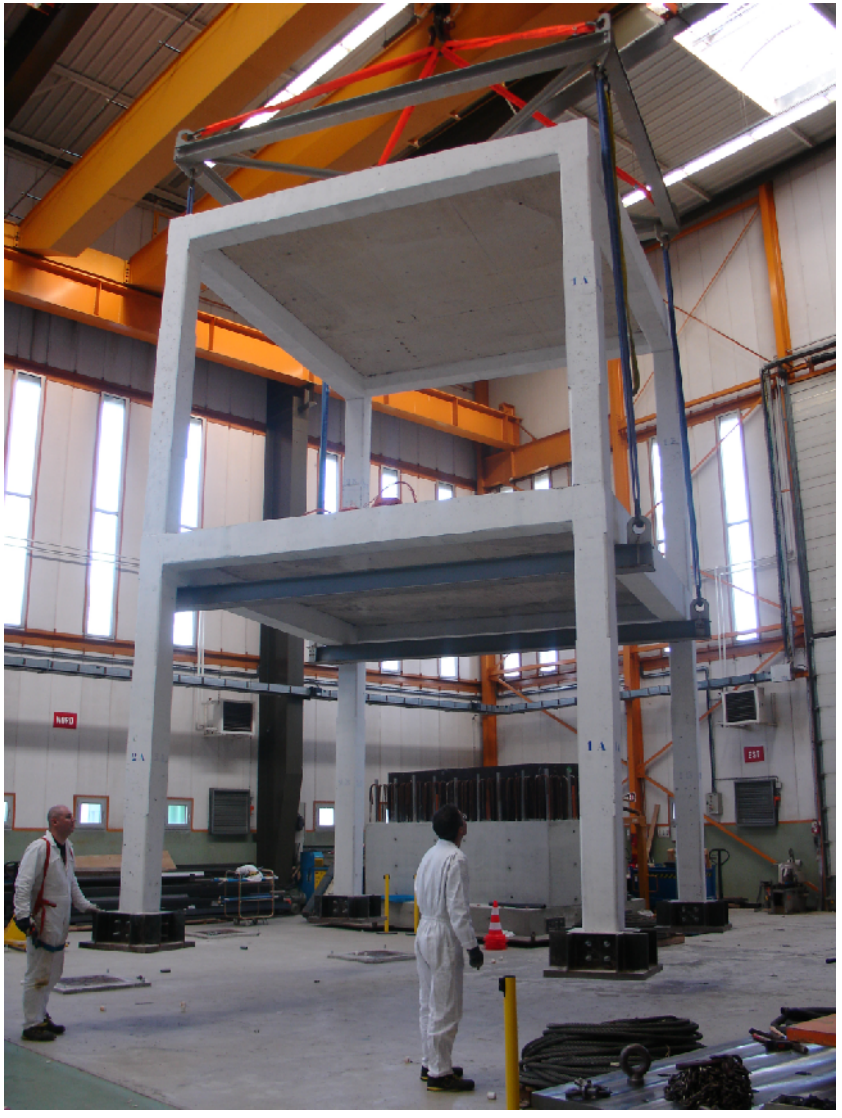
Column Foot (Base Plate)



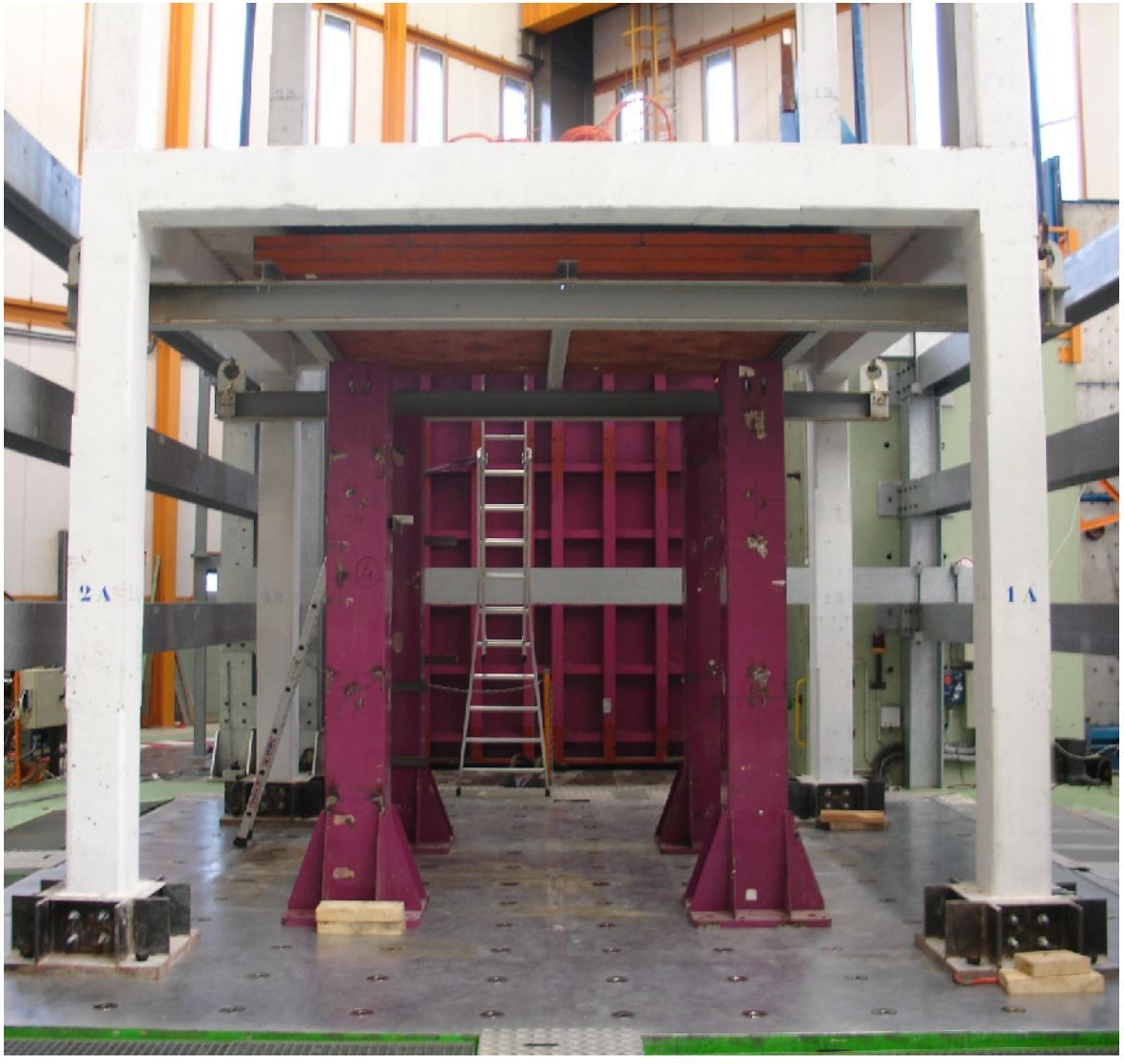
Strain-Gage Installation

Concrete Batch

Transferring the Specimen



Specimen on the Shaking Table



BANDIT (SERIES project)

Expected Results

- Acquire a better understanding on the seismic behaviour of typical substandard RC structures.
- Develop cost efficient rehabilitation strategies for seismic strengthening of poor quality beam-column joints using PTMS.
- Develop design guidelines for assessment and seismic strengthening of substandard building structures.

Acknowledgment

The authors would like to acknowledge the invaluable support from **SERIES** programme and especially **Professor M.N. Fardis**.

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Thank you for your attention